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**CONTINUOUS OPERATION METHOD FOR A TOMOGRAPHY DEVICE**  
**AND CORRESPONDING TOMOGRAPHY DEVICE**

5 The invention lies in the field of imaging tomography apparatuses, in particular for medical examinations, in particular in the field of x-ray computer tomography (CT), single photon emission tomography (SPECT) or positron emission tomography (PET).

10 The invention concerns a method for operation of a tomography apparatus which comprises a scanning unit that can rotate around a system axis and a bearing device for an examination subject.

The invention also concerns a tomography apparatus with a scanning unit that can be rotated around a system axis, a control device for activation of the scanning unit  
15 and a bearing device for an examination subject.

The implementation of examinations on a plurality of examination subjects or patients by means of an x-ray computer tomography apparatus was previously, for example, conducted as follows:

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1. generation of an x-ray shadow image (topogram, scanogram, scout view) with a non-rotating x-ray source, whereby a first examination subject is moved on the bearing device relative to x-ray source and detector system in the direction of the system axis,
- 25 2. definition of the region (scan region) of the first examination subject to be acquired in the direction of the system axis in the actual examination on the basis of the generated x-ray shadow image,
3. positioning of the first examination subject by moving the bearing device to the start point of the scan region,
- 30 4. start of the rotation of the x-ray source around the system axis,

5. implementation of the actual examination of the first examination subject in the form of a slice and/or volume scan with a rotating x-ray source, for the most part in the form of a spiral scan,
6. interruption of the rotation of the x-ray source and
- 5 7. repetition of the steps 1 – 6 with the next examination subject.

Among other things, with the topogram it should be achieved that, with regard to a minimization of the radiation dose, projection data are no longer acquired (for example in the spiral scan), thus a larger region is scanned than would then be  
10 actually necessary for the subsequent image reconstruction in the desired region. Moreover, the topogram serves as the documentation of the scanned region.

In principle this method included some disadvantages:

- a) The entire workflow proves to be relatively long, which is undesirable for efficiency reasons and for medical reasons, in particular when it is an  
15 emergency patient.
- b) If x-ray shadow images are desired from various projection directions (viewing angles), for example “from the front” and “from the side”, the patient is moved three times with the bed, namely twice for generation of  
20 the shadow images and a third time for the spiral scan.

For optimization of the workflow and the flexibility, what are known as “growing topograms” have therefore been proposed, whereby an x-ray shadow image is acquired and displayed simultaneously or inline with the spiral scan, which x-ray  
25 shadow image grows with the spiral scan. Such a procedure is described in DE 198 02 405 A1 for a computer tomography apparatus with what is known as a 2-tube system. Computer tomographs with only one x-ray radiator have also been proposed in which the topogram likewise exists quasi-“online” via extraction of data that accrue during the actual scanning from a plurality of directions, for  
30 example in the spiral scan. Such methods are known from EP 0 531 993 B1, DE 41 03 588 C1 and DE 199 25 395 A1.

From the cited documents it is also known to allow the or one of the x-ray tubes to only emit in a pulse fashion at the projection angle or angles necessary for a tomogram.

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Moreover, in EP 1 116 475 A1 what is known as a synthetic topogram is proposed that is generated in that, initially, a 3D data set is reconstructed from the projection data sets and that the shadow image is subsequently calculated from the 3D data set.

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The invention is based on the object to upgrade a method as well as a tomography apparatus of the previously-cited type so that the entire workflow can be executed more quickly in the examination of a plurality of patients.

15 This object is achieved according to the invention and is related to the previously cited method in that the rotation of the scanning unit is not interrupted from the beginning of the examination of a first examination subject until the end of the examination of a second examination subject.

20 The invention thereby starts from the consideration that times for braking or for starting up the scanning unit have a significant proportion of the overall time span necessary for examination of a plurality of patients. For example, the braking and start-up time for the rotating gantry of a CT is respectively approximately 0.5 to 1 minute. This is due in part to large rotating mass that necessitates a ramp-like  
25 positive or, respectively, negative acceleration as well as waiting for a mechanical and/or electrical swinging-in or swinging-out of the bearing parts or, respectively, of the actuators. This problem still increases immensely with increasing rotation speed.

30 Corresponding downtimes arise, for example, before the beginning of the slice and/or volume scanning of the examination subject, in the event that the rotation of

the scanning unit is then started up and, after the end of the scanning, in the event that the rotation is then interrupted until the examination of the next examination subject. The invention is based on the realization [sic] to prevent such downtimes via continuous rotation of the scanning unit. In particular the scanning unit rotates  
5 in the change from one examination subject to the next examination subject.

In addition to the acceleration of the entire workflow in the examination of a plurality of patients, the following advantages result with the method according to the invention:

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i) The control of the tomography apparatus can be significantly simplified. In particular a repositioning (scanning unit with regard to bearing device, horizontal and vertical) that has been necessary up to now before each new examination can be omitted, or is at least significantly simplified. The  
15 electrical activation of the rotation-driving motors is also simplified.

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ii) The measurement times are also reduced by the permanent rotation, which above all else is then significant when a tomography apparatus is used for emergency patients, whereby every second counts. Here the advantages are  
20 obvious, even when only 1 – 2 minutes can be saved.

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iii) the load for the bearing components of the tomography apparatus is reduced. The lubrication of bearings is also improved by the evened-out movement.

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iv) The temperature stability and homogeneity of the entire tomography apparatus is improved. This in particular also has an effect in the data acquisition system. The cooling is also thereby simplified.

30 The interruption-free rotation of the scanning unit can mean a rotation with constant speed. However, the rotation speed or the rotation frequency is preferably

set differently dependent on the type of the desired examination (application), for example for an examination of the heart or of the abdomen of a patient.

5 The tomography apparatus is in particular controlled such that, in the event that no examination directly occurs, the scanning unit then rotates with a preset rotation speed ("standby setting"). This rotation speed (rest rotation speed) is, for example, smaller than the rotation speeds available for the applications or lies in the range of the average value of the rotation speeds available for the applications, such that the change of the rotation speed given a new application is on average small.

10 The rotation speed is preferably continuously changed between the different applications or between an application and the rotation in standby setting.

15 According to a preferred embodiment of the method, the time span of the uninterrupted rotation of the scanning unit extends over a work shift, over a working day or over a plurality of examinations. The shift or, respectively, the working day concern, for example, the medical establishment with which the tomography apparatus is associated. The time span of the uninterrupted rotation can also extend over a week or longer.

20 According to a preferred embodiment of the method, the time span of the uninterrupted rotation of the scanning unit extends over at least one hour or over at least three hours.

25 With regard to the particularly long time spans of the uninterrupted rotation, it is particularly advantageous embodiment in the event that a calibration of the tomography apparatus (in particular comprising a position and/or reception channel correction) is effected during the rotation of the scanning unit. The invention is thereby based on the realization that such a procedure consequently has  
30 significantly fewer inaccuracies than is the case given calibration in the downtime and subsequent testing upon rotation. A continuously-rotating measurement

system namely also has the advantage that the mechanical inaccuracies created due to centrifugal forces, for example a deflection of the measurement system, carry significantly less weight, in particular when these are equally allowed for in the calibration.

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In a particularly advantageous embodiment, the tomography apparatus is an x-ray computer tomography (CT) apparatus whose scanning unit comprises an x-ray source that can be rotated around the system axis and a detector system for acquisition of the x-ray radiation emanating from the x-ray source, whereby at least  
10 the rotation of the x-ray source – and optionally also that of the detector system – is not interrupted from the beginning of the examination of a first examination subject to the end of the examination of a second examination subject.

The necessity of the interruption of the rotation was previously often derived from  
15 the fact that a topogram should have been acquired for the previously explained reasons. The invention here arises from the additional realization that nevertheless no interruption of the rotation of the scanning unit is necessary for a topogram, even in the event that it should be completely finished before the actual CT scanning examination subject. This is clarified by the following three preferred  
20 embodiments:

- 1) The examination of the first and/or second examination subject comprises the following method steps:
  - a) acquisition of an x-ray shadow image of the examination subject given  
25 rotating x-ray source,  
*and then:*
  - b) implementation of a slice and/or volume scanning of the examination  
subject with a rotating x-ray source, whereby the x-ray source emits x-ray  
radiation at a plurality of angle positions and respective projection data are  
30 detected by the detector system,

and whereby the rotation of the x-ray source is not interrupted from the beginning of the step a) to the end of the step b).

In spite of uninterrupted rotation, a topogram can thereby be generated that is  
5 concluded before the actual CT examination (step b).

The x-ray source thereby in particular respectively emits x-ray radiation in a *pulsed manner* at an angle position that can be predetermined for the x-ray shadow image for acquisition of the x-ray shadow image in step a), and corresponding  
10 radiographic data are detected by the detector system. The x-ray source can simultaneously be moved parallel to the system axis and relative to the examination subject. This relative movement can possibly be omitted given a corresponding detector system expanded in the direction of the system axis.

- 15 2) The examination of the first and/or second examination subject comprises the following method steps:
- a) implementation of a slice and/or volume scanning of the examination subject with a rotating x-ray source, whereby the x-ray source emits x-ray radiation at a plurality of angle positions and respective projection data are  
20 detected by the detector system, and whereby in particular the x-ray source is moved parallel to the system axis and relative to the examination subject;
  - b) generation of an x-ray shadow image of the examination subject *simultaneously* with the slice and/or volume scanning, in that matching projection data are selected for the x-ray shadow image from the data  
25 accumulating in the slice and/or volume scanning.

Given an uninterrupted rotation, a mutually growing topogram can thereby be generated. Given a corresponding detector system extended in the direction of the system axis, the relative movement of the x-ray source parallel to the system axis  
30 can possibly be omitted.

- 3) The examination of the first and/or second examination subject comprises the following method steps:
- a) implementation of a slice and/or volume scanning of the examination subject with a rotating x-ray source, whereby the x-ray source emits x-ray radiation at a plurality of angle positions and respective projection data are detected by the detector system, and whereby in particular the x-ray source is moved parallel to the system axis and relative to the examination subject;
  - b) reconstruction of a 3D data set from the projection data accumulating in the slice and/or volume scan;
  - c) calculation from the 3D data set of an x-ray shadow image of the examination subject as a synthetic projection image.

*A synthetic topogram* can thereby be generated given uninterrupted rotation. Given a corresponding detector system extended in the direction of the system axis, the relative movement of the x-ray source parallel to the system axis can possibly be omitted.

In the method according to the invention, the slice and/or volume scan can ensue in the form of a spiral scan according to a particularly preferred embodiment. For this, the bearing device on the one hand and the x-ray source and the detector system on the other hand can be movable relative to one another, at least significantly in the direction of the system axis, given displacement of the x-ray source around the system axis.

The apparatus-related object is achieved according to the invention in that the control device of the previously-cited tomography apparatus is fashioned such that the scanning unit can be rotated without interruption from the beginning of the examination of a first examination subject until the end of the examination of a second examination subject.



Advantages and preferred embodiments of the tomography apparatus according to the invention apply analogous to as for the method of the invention.

5 The tomography apparatus according to the invention is preferably fashioned as an x-ray computer tomography (CT) apparatus. It can also be fashioned as a single photon emission tomography (SPECT) apparatus or as a positron emission tomography (PET) apparatus or as a combination of such apparatuses, for example as a PET/CT apparatus. The method according to the invention is also applicable for such apparatuses.

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According to a preferred exemplary embodiment, the scanning unit comprises an x-ray source that can be rotated around a system axis and a detector system for acquisition of the x-ray radiation emanating from the x-ray source, whereby the control device is fashioned such that at least the x-ray source – and optionally also  
15 the detector system – can be rotated without interruption from the beginning of the examination of a first examination subject until the end of the examination of a second examination subject.

The tomography apparatus is also preferably arranged for a continuous operation  
20 with regard to the electrical power supply to the x-ray generator and/or with regard to the heat dissipation, in particular the cooling of the rotating scanning unit.

For this, the cooling device preferably comprises, for example, air drivers for generation of an air flow, whereby the air drivers are mounted on a rotating frame  
25 bearing the scanning unit and dimensioned such that a cooling capacity sufficient to cool the scanning unit is achieved upon rotation of the rotating frame. Special ventilators to be driven electrically can thereby be omitted. This idea is also advantageously applicable in a tomography apparatus that does not rotate continuously.

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The air drivers are in particular fashioned as air scoops that can be mounted inside the rotating frame, for example acting in an annular current channel, or preferably on an outside of the rotating frame or on an outside of a housing wall of the rotating frame.

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The invention is subsequently explained in detail using exemplary embodiments shown in schematic Figures. Thereby shown are:

- |    |        |   |
|----|--------|---|
| 10 | Fig. 1 | in partially perspective, partially block-diagram-like representation, a CT apparatus suitable for implementation of the inventive method,        |
|    | Fig. 2 | a block diagram for illustration of an exemplary embodiment of the inventive method,  |
| 15 | Fig. 3 | a diagram with a time curve of the rotation speed of a scanning unit of the CT apparatus of Figure 1 in the exemplary embodiment of Figure 2, and |
| 20 | Fig. 4 | a detail of a CT apparatus according to the invention concerning the cooling.   |

A CT apparatus of the 3rd generation suitable for implementation of the inventive method is shown in Figure 1 under omission of, among other things, a housing frame. The scanning unit or measurement arranged of the CT apparatus  
25 (designated overall with 1) comprises an x-ray source 2 and a detector system 5 fashioned as a laminar array of a plurality of rows and columns of detector elements 4. The x-ray source 2 and the detector system 5 are mounted opposite one another on a rotating frame (not shown), such that a pyramidal x-ray beam with edge rays 8, emanating (in the operation of the CT apparatus) from the x-ray  
30 source 2 and gated by adjustable ray diaphragms, impinges on the detector system 5.

The rotating frame (gantry) can be displaced in rotation around a system axis Z by means of the actuation device 7 fashioned as a synchronous motor or alternatively as an asynchronous motor with belt drive. The system axis Z runs parallel to the z-axis of a spatially-rectangular coordinate system shown in Fig. 1.

The columns of the detector system 5 likewise run in the direction of the z-axis while the rows (whose width b is measured in the direction of the z-axis and is, for example, 1 mm) run transverse to the system axis Z or, respectively, the z-axis.

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In order to be able to bring an examination subject (for example a patient) into the beam path of the x-ray beam, a bearing device 9 is provided that can be moved parallel to the system axis Z, thus in the direction of the z-axis, and in fact such that a synchronization exists between the rotation movement of the rotating frame and the translation movement of the bearing device 9 in the sense that the ratio of translation speed to rotation speed is constant, whereby this ratio can be adjusted in that a desired value is selected for the feed h of the bearing device 9 per rotation of the rotating frame.

20 A volume of an examination subject located on the bearing device 9 can thus be examined in the course of a volume scan, whereby the volume scan is effected in the form of a spiral scan in the sense that a plurality of projections is acquired from various projection directions under simultaneous rotation of the scanning unit 1 and translation of the bearing device 9 by means of the scanning unit 1 per revolution of the scanning unit 1. In the spiral scan, the focus F of the x-ray source moves on a spiral path S relative to the bearing device 9.

The measurement data read out in parallel from the detector elements 4 of each row of the detector system 5 during the spiral scan and corresponding to the individual projections are serialized in a sequencer 10 and transferred to an image computer 11.

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After a pre-processing of the measurement data in a pre-processing unit 12 of the image computer 11, the resulting data stream arrives at a cross-section reconstruction unit 13 that reconstructs from the measurement data slice images of  
5 desired slices of the examination subject according to a known method (for example 180LI or 360LI interpolation).

In order to be able to determine the position of the slice (with regard to which a cross-section should be reconstructed) in the z-direction, an x-ray shadow image  
10 can also be reconstructed in addition to cross-sections. For this, the portion of the measurement data necessary for reconstruction of an x-ray shadow image is extracted from the data stream coming from the sequencer 10 by means of a filter 14, and in fact before this arrives at the cross-section reconstruction unit 13, and supplied to an x-ray shadow image reconstruction unit 15 that reconstructs an x-ray  
15 shadow image from the extracted measurement data according to a known method.

The section or, respectively, x-ray shadow images reconstructed by the cross-section reconstruction unit 13 and the x-ray shadow image reconstruction unit 15 during the implementation of the spiral scan are shown parallel to and synchronous  
20 with the spiral scan on a display unit 16 (for example a video monitor) connected to the image computer 11.

The x-ray source 2, for example an x-ray tube, is supplied with the necessary voltages and currents by a generator unit 17. In order to be able to adjust this to  
25 the respectively necessary values, a control device 18 with keyboard 19 is associated with the generator unit 17, which control device 18 allows the necessary adjustments. The generator unit 17 also allows an intermittent or pulse-like emission of x-rays at predeterminable angle positions of the x-ray source 2. The angle positions (projection directions) are generated by a position sensor with a  
30 chopper.

The other operation and control of the CT apparatus also ensues by means of the control device 18 and the keyboard 19, which is illustrated in that the control device 18 is connected with the image computer 11. The control device 18 moreover serves for the activation of the drive device 7.

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The design of the image computer 11 is described in the preceding in a manner of hardware components, as are the pre-processing unit 12, the cross-section reconstruction unit 13, the filter 14 and the x-ray shadow image reconstruction unit 15. This can in fact be so, however normally the cited components are realized by software modules that run on a universal computer provided with the necessary interfaces, which universal computer can also (deviating from Fig. 1) assume the function of the control device 18.

15 The generator unit 17 and the drive device 7 allow the following operating modes that can be adjusted by means of the control unit 18:

- 20 V: continuous operation of the x-ray source 2 in volume scanning, for example spiral scanning, with an x-ray power parameterized for the generation of slice images,
- T': continuous operation of x-ray source 2 in spiral scanning with an x-ray power parameterized for the generation of x-ray shadow images (topogram) and reduced relative to the operating mode "V",
- 25 T: activated operation of the x-ray source 2, whereby the x-ray source 2 radiates an x-ray pulse with the x-ray power parameterized for the generation of x-ray shadow images only when the rotating x-ray source 2 is located in a position corresponding to the desired projection direction for the x-ray shadow image (topogram), and

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A: disconnected operation, in which the x-ray source 2 does in fact rotate with constant rotation frequency  $f_A$  ( $>0$ , for example 1 rotation/s) (“standby mode”) but is not activated.

5 Figures 2 and 3 shows a simplified flow diagram or, respectively, a time diagram of the workflow in the examination of a plurality of examination subjects U1, U2, ... Examination subjects as such are not shown – rather, “U1” or, respectively, “U2” designate what respectively belongs to the examination of the appertaining examination subject. Figure 2 schematically shows the curve of the rotation  
10 frequency  $f_{\text{Rot}}$  with the time  $t$  during the workflow. The  $t$ -axis is not scaled linearly: as a rule a spiral scan will take longer, in comparison with a topogram acquisition, than as shown here.

A calibration step “Cal” is executed at the beginning of a workday or a work week.  
15 The control device 18 subsequently brings the scanning unit 1 into rotation in a first park or standby phase 21 with the operating mode “A” in which the CT apparatus remains available until a first examination subject U1 for examination. In the operating step “T”, the examination is then begun with a topogram step 22 without interruption of the rotation. Only an x-ray shadow image (topogram) of  
20 the first examination subject U1 – or alternatively two shadow images laterally and a.p. [sic] – is reconstructed and displayed. Without interruption of the rotation, in a further standby phase 23 the apparatus is subsequently switched again into the operating mode “A” during which the operating personnel initially establishes a diagnostically-relevant scan region and then, using this, positions the first  
25 examination subject U1 at the beginning of the desired scan region. After an occurred positioning, a spiral scan is implemented under continuous rotation in the operating mode “v” in a volume scan step 24 with rotation speed negligibly increased relative to step 23. If the prior established end of the scan region is reached, without interruption of the rotation the scanning unit 1 is switched again  
30 into the operating mode “A” in a further standby phase 25 and the radiation is

deactivated, whereby the scanning unit 1 rotates further, however. The CT apparatus remains in this state until a further patient should be examined.

The procedure is subsequently repeated as needed with a second examination  
5 subject U2, whereby here in the example a different region of the patient should be examined (different application):

- topogram step 26,
- standby phase 27 with positioning of the second examination subject U2 for  
10 the subsequently
- volume scan 28 with a rotation frequency less – due to the different application – in comparison to the examination of the first examination subject U1,
- standby phase 29.

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The cycles are subsequently repeated again with further examination subjects, whereby the scanning unit 1 rotates without interruption over a time span  $\Delta t$  of a plurality of hours. The scanning unit 1 can also rotate during the calibration step Cal, which is different than is shown in Figures 2 and 3.

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As an alternative to the operating mode “T”, at the beginning of the examination parallel x-ray shadow image reconstruction and cross-section image reconstruction can be implemented in the operating mode “T”. The results are shown in parallel on the display unit 16. Due to the reduced x-ray power, the cross-sections can,  
25 however, only be diagnostically used in a limited manner.

In the implementations made up to Figures 2 and 3, it was assumed that the topogram is completely concluded before the actual volume scan, that both beginning and end of the diagnostically-relevant scan region are thus known. As  
30 an alternative to this, the topogram can also respectively be generated only in part before the volume scan is begun: namely, if diagnostically-relevant structures are

achieved in the operating mode “T” or “T” with increasing z-feed of the scanning unit 1, the scanning unit 1 can be switched to the operating mode “V” without interruption of the rotation, in which operating mode “V” measurement data are now acquired that (due to the now-higher x-ray power) enable the reconstruction of slice images of higher quality that are simultaneously displayed with the x-ray shadow image. If the diagnostically-relevant region has been scanned, in this alternative the scanning unit 1 is also switched again into the operating mode “A” in a further standby phase 25 without interruption of the rotation of the scanning unit 1 and the radiation is deactivated, whereby the scanning unit 1 still rotates further.

In a further alternative operating mode that is particularly of importance for CT apparatuses whose detector system 5 exhibits a large width in the direction of the system axis Z and therewith comprises a large number of rows, a relative movement between the scanning unit 1 and the bearing device 9 in the direction of the system axis Z (and therewith a spiral scan) can also be foregone when the extent of the detector system 5 is sufficient in order to acquire the entire region to be examined. For the case that the extent of the detector system 5 in the direction of the system axis Z is greater than the corresponding extent of the region to be examined, it is thereby sufficient to activate only those rows the detector system 5 that are necessary for acquisition of the examined region.

The rotation operation of the rotating mass in an x-ray computer tomography (CT) apparatus would therefore have to have previously fulfilled two criteria:

1. a precise adjustment of a rotation frequency according to specification and
2. a positioning of the mass at a specific angle position.

In terms of regulation technology, both requirements are very difficult to fulfill together, so that in the past the rotation speed regulation, which is decisive for the imaging in a spiral scan, would often have to take precedence. Given application of only a simple position method, a plurality of attempts (for example via braking



the mass with a correction angle and studying the braking path) and therewith more time could therefore be necessary in order to achieve the goal. In the individual case, the angle precision would thereby amount to only approximately  $\pm 5^\circ$ .

5 Advantages of the continuous rotation are now that

A) only a constant rotation speed must still be regulated, i.e. the regulation system can be executed comparably simply and the actuator can, for example, be reduced to a very inexpensive asynchronous motor, and that

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B) the precision of the angle adjustment for a topogram is significantly higher, thus the subdivision of an angle of the rotation position transmitter (and therewith in particular the result of the generated overview image) is more precise.

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A continuously-rotating measurement system also effects a uniform temperature distribution and thereby allows an increased measurement precision, thus a better image quality. A continuously-rotating measurement system prevents “temperature peaks”, i.e. locally pronounced temperature increases that can attract attention to themselves via mechanical warpings of the measurement system in the form of measurement inaccuracies, for example via distortion of the beam fan relative to the detector, and/or can lead to an increased mechanical wear, for example of a bearing.

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25 A continuous rotation also allows the rotating measurement system to be shaped such that it is actively participating in the cooling in that, for example, the mounting or the rotating frame 40 of the measurement system is designed so that it acts as a ventilator. For this – as shown schematically in Figure 4 – air scoops 43 can be present on the outside (front side or circumferential side) of a housing 41 of the rotating frame 40 as a part of a cooling device 42. The air current required for cooling in operation can then be generated without additional ventilators. To

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prevent injuries, the air scoops 43 can be covered either by stand frame 45 of the CT apparatus or by a special covering (grid network etc.)

5 The invention can be applied within but also outside of medicine, for example also in package checking or in material examination.